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NAVY EXPERIMENTAL DIVING UNIT
Panama City, Florida 32407

NAVY EXPERIMENTAL DIVING UNIT
REPORT NO. 12-78

EX-17 UNDERWATER BREATHING APPARATUS

March 1978

D.J. SCHMITT

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The EX-17 Underwater Breathing Apparatus (UBA) was assembled and tested by the Navy Experimental Diving Unit (NEDU) to determine the suitability of a closed-circuit apparatus for deep diving applications and as a tool for in-house physiological function studies. The EX-17 is a modified version of the Swimmer Life Support System (SLSS) MK 1, a closed-circuit, mixed-gas, self-contained UBA. The EX-17 configuration includes a dry helmet CONT

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and umbilical gas supply. The EX-17 is intended to operate at depths to 2,000 feet of seawater (fsw) in the usual closed circuit mode, and in an emergency open circuit mode. Preliminary tests were successful despite minor technical problems. During Deep Dive 77, the EX-17 demonstrated capability to support a diver doing light, moderate, and heavy work at depths from 1,054 to 732 fsw. NEDU is performing further investigations to insure EX-17 UBA life support capability and mission reliability at depths to 2,000 fsw.

SUMMARY

The EX-17 Underwater Breathing Apparatus (UBA) was assembled and tested in-house by the Navy Experimental Diving Unit (NEDU). The EX-17 UBA is a modified version of the Swimmer Life Support System (SLSS) MK 1, a self-contained, closed-circuit, mixed-gas UBA developed under Technical Development Plan 38-02, The Swimmer Support System.

The first section of this report provides the background for EX-17 development. Primary advantage of the EX-17 closed-circuit system is the recycling of the inert diluent in the breathing gas while metabolic oxygen is maintained at pre-set levels and carbon dioxide removed by canister absorbent. The apparatus has proved safe and the design allows breathing circuits which are of low resistance. The neutrally buoyant, hydrodynamically styled backpack promotes diver efficiency and mobility. Also, the EX-17 requires minimum equipment maintenance as compared to other units designed for very deep diving.

As a direct variant of the SLSS MK 1, the EX-17 UBA constitutes an engineering tool for future research in deep diving. The EX-17 is intended to operate at depths to 2,000 feet of sea water (fsw) in the primary sensor-controlled, closed-circuit mode, and an emergency open circuit mode. Section II documents modifications made to the SLSS MK 1 to meet these operating requirements. An umbilical supply was added providing a communications cable, gas hose, life line, surface alarm cable, and hot water hose. A surface readout/alarm

unit and O_2 sensor electrical leads were incorporated in the electronics assembly. The EX-17 configuration includes a dry helmet, hot water envelope, and emergency gas supply to permit operation at depths to 2,000 fsw. O_2 and diluent gas bypasses were removed and necessary piping changes made.

EX-17 system evaluations and test results are discussed in Section III. Preliminary tests successfully established system life support and mission reliability characteristics. During Deep Dive 77, physiological functions of working divers were monitored at depths between 1054 and 732 fsw. Results demonstrated the EX-17 can support a diver doing light, moderate, and heavy work at these depths. Diver confidence in the system was good.

Canister breakthrough (inspired pCO_2 exceeded 0.5% SEV) indicated a CO_2 scrubber duration of 1-1/4 hours because of technical problems (i.e., a broken thermistor made measurement of CO_2 scrubber temperature impossible and holes in the hot water envelope precluded heating canister gas).

Section IV presents conclusions and recommendations for future system development, including improvements to the CO_2 scrubber, dry helmet, and hot water envelope. In its present configuration, the EX-17 can meet much broader mission requirements at greater depths than its SLSS MK 1 predecessor. However, further investigation is necessary to insure EX-17 life support and mission reliability at depths to 2,000 fsw. The EX-17 UBA is best suited for use with a personnel transfer capsule (PTC) in saturation diving missions.

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INTRODUCTION

DESIGNATION

In the 1976-1977 timeframe, it became apparent that mission requirements of the Special Warfare (SPECWAR), Explosive Ordnance Disposal (EOD), and deep diving communities could all potentially be met by variants of the Biomarine Industries' CCR-1000 Underwater Breathing Apparatus (UBA). The SPECWAR variant, initially designated the Swimmer Life Support System (SLSS) MK 1, is a reality. The EOD variant, called the Low Influence Diving System (LIDS), is currently under development by EODFAC. In an original attempt to standardize terminology, the Navy Experimental Diving Unit (NEDU) proposed a MK 15 UBA family be designated encompassing all three CCR-1000 variants. While awaiting response to this suggestion, NEDU adopted the in-house term, Deep Diving MK 15 UBA or Deep 15 for the deep diving variant until such time as an official title should evolve. Deep 15 was considered a preferred title to such acronyms as Deep Umbilical Diving System (DUDS). Finally, in March of 1978, the SLSS MK 1 was formally redesignated the MK 15 UBA although the former acronym has been retained in this report. At the same time Deep 15 was discarded in favor of EX-17 in anticipation of a future MK 17 UBA designation.

SCOPE

This report documents the in-house assembly and testing of the EX-17 UBA by NEDU. Section 1 provides the background for assembling the Deep 15 configuration of the SLSS MK 1. Modifications made to the SLSS MK 1 to meet EX-17 mission and operating requirements are discussed in Section II. Section III describes

system evaluations and test results. Conclusions and recommendations for further investigative effort are made in Section IV.

BACKGROUND

Mission requirements and the high cost and logistic problems associated with large quantities of helium in deep diving operations have made development of a closed-circuit diving system most attractive. The U.S. Navy has been testing closed-circuit systems since the 1960's under Technical Development Plan (TDP) 38-02, The Swimmer Support System. In 1972, the Navy initiated tests on the CCR-1000 closed-circuit mixed-gas system manufactured by Biomarine Industries, Inc. This system was adapted for use by the U.S. Navy and designated the SLSS MK 1.

SLSS MK 1 CONFIGURATION

The SLSS MK 1 is a closed-circuit, mixed-gas, self-contained underwater breathing apparatus (scuba). A battery operated electronic module maintains the swimmer's breathing gas at a predetermined partial pressure of oxygen (pO_2) via three oxygen sensors which measure and evaluate the pO_2 level. When an O_2 deficiency is indicated, the electronic module activates the solenoid valve in the oxygen pressure system to supply O_2 within ± 10 percent of the preset pO_2. Appendix A provides a detailed description of the MK 1 system.

THE EX-17 CONFIGURATION

The SLSS MK 1 has proved effective in evaluations to depths of 200 feet for dives six hours in duration. Because the system uses little gas and provides the diver with a high degree of mobility for bottom operations, the configuration is being investigated for use at much greater depths. With its proven reliability, the SLSS is a logical candidate for missions at depths to 2,000 feet of seawater (fsw). The MK 1 configuration, however, requires certain modifications to make it suitable for deep diving, notably the addition of an umbilical supply and dry helmet. The EX-17 UBA (Figure 1-1) incorporates major changes to the present SLSS MK 1.

In September 1976, NEDU procured two Biomarine CCR-1000 units and adapted them for the deep diving operational modes; a primary closed-circuit mode with umbilical supplied make up of respirable diluent and an emergency open circuit mode where the respirable diluent is supplied directly to the helmet by the umbilical. Under normal operating conditions, the EX-17 is in the closed-circuit mode with umbilical-supplied respirable gas automatically added as needed by the Schrader valve. The O_2 sensors and O_2 bottle supply maintain the preset pO_2 level. The diluent bottle provides a respirable emergency gas supply for closed-circuit operation in case of loss of umbilical.

Helmet open-circuit is manually operated by the diver if additional respirable gas is needed to ventilate the helmet or to clear the helmet in case of flooding. The EX-17 is operated

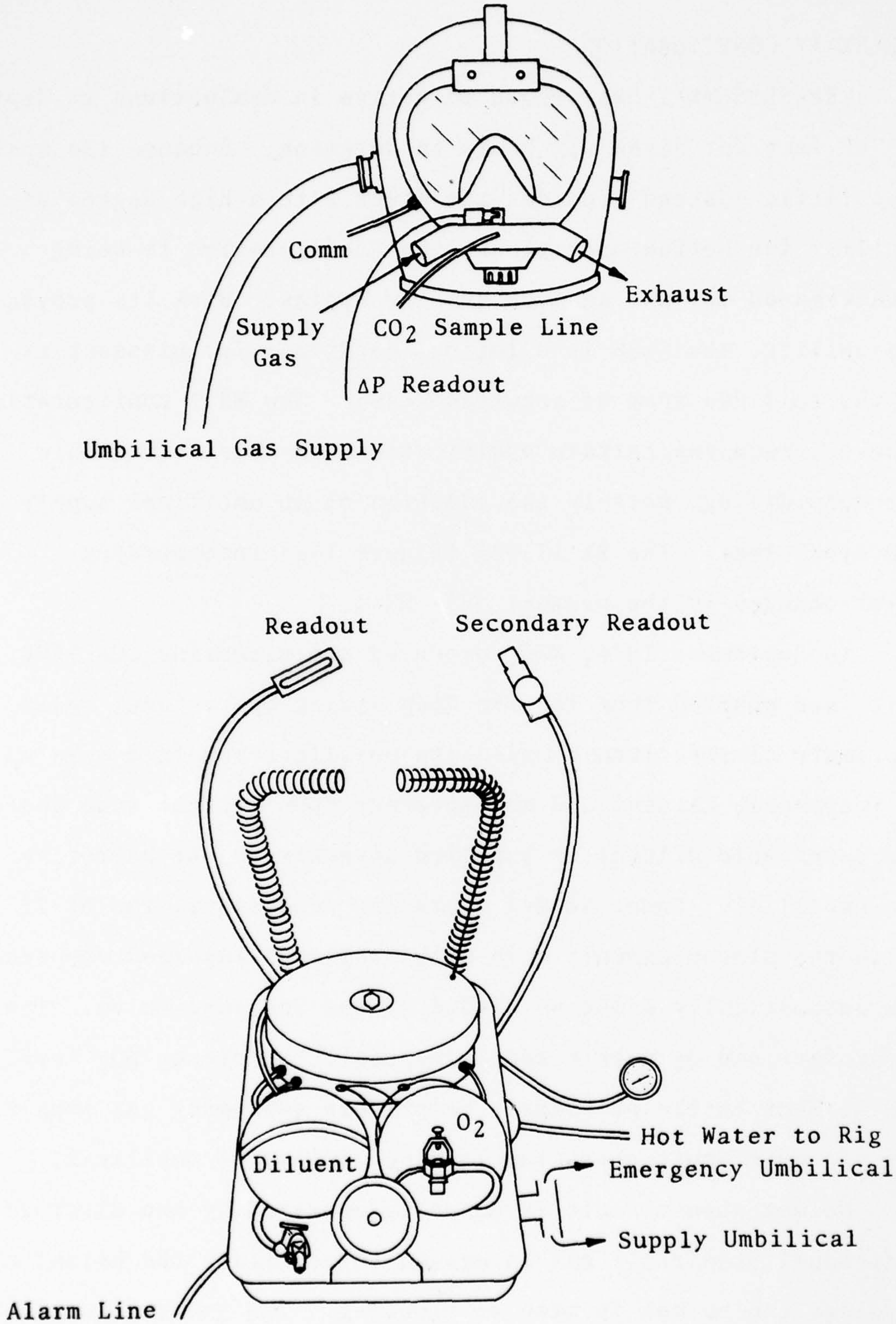

Figure 1-1. EX-17 UBA (With General Aquadyne Helmet)

in the open-circuit mode only in an emergency. Gas supply is solely from the umbilical. When open-circuit operation is initiated by opening the helmet gas supply valve, the diver must return to the PTC.

NEDU began EX-17 testing and evaluation in 1976 (reference Section III of this report). Specific SLSS modifications embodied in the EX-17 UBA are outlined in the next section.

SECTION II

EQUIPMENT MODIFICATIONS

This section describes modifications made to the Biomarine CCR-1000 units to meet potential EX-17 operating requirements. Figures 2-1 and 2-2 are schematics of the SLSS MK 1 and EX-17 showing the basic configuration differences. A set of drawings (reference NEDU EX-17 UBA drawing package) documents each equipment modification. Appendix B provides a complete equipment listing for the EX-17 configuration.

UMBILICALS

The operation of the EX-17 necessitates an umbilical gas supply. Standard-length (100 foot) umbilicals were added to the MK 1 configuration, including a communications cable, gas hose, life line, surface alarm cable, and hot water hose. Use of the umbilicals provides surface communications, pO_2 monitoring, and solenoid monitoring. Surface-supplied/PTC gas to make up the volume in the breathing loop is also provided by the umbilical as well as the emergency open-circuit mode.

DRY HELMET

The EX-17 UBA is used with a General Aquadyne DMC-7 helmet (Figure 2-2) in place of the SLSS MK 1 mouthpiece assembly. (A more compatible helmet is being assembled for the EX-17 configuration, as described in Section IV.) The helmet's oral nasal assembly is designed to prevent CO_2

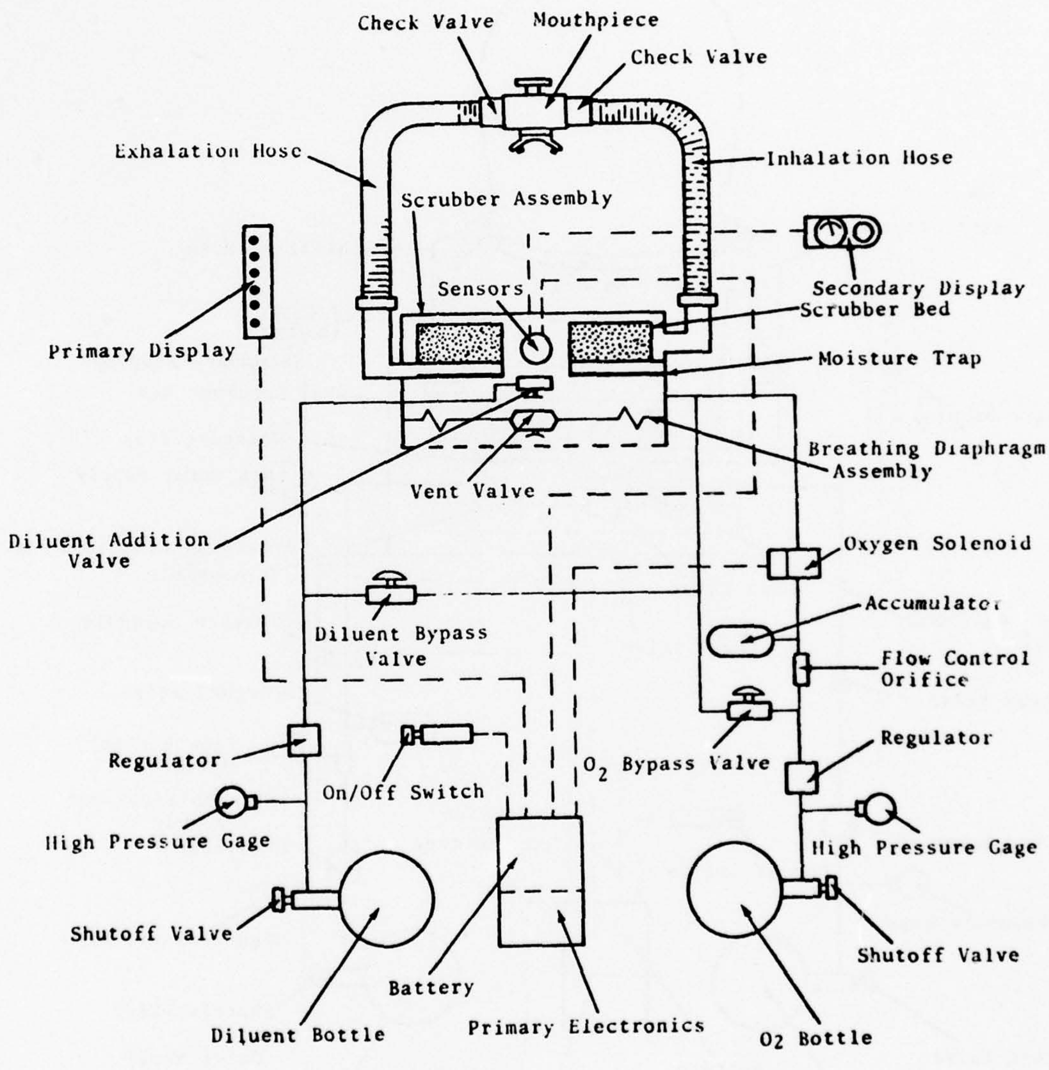

Figure 2-1. SLSS MK 1 Schematic

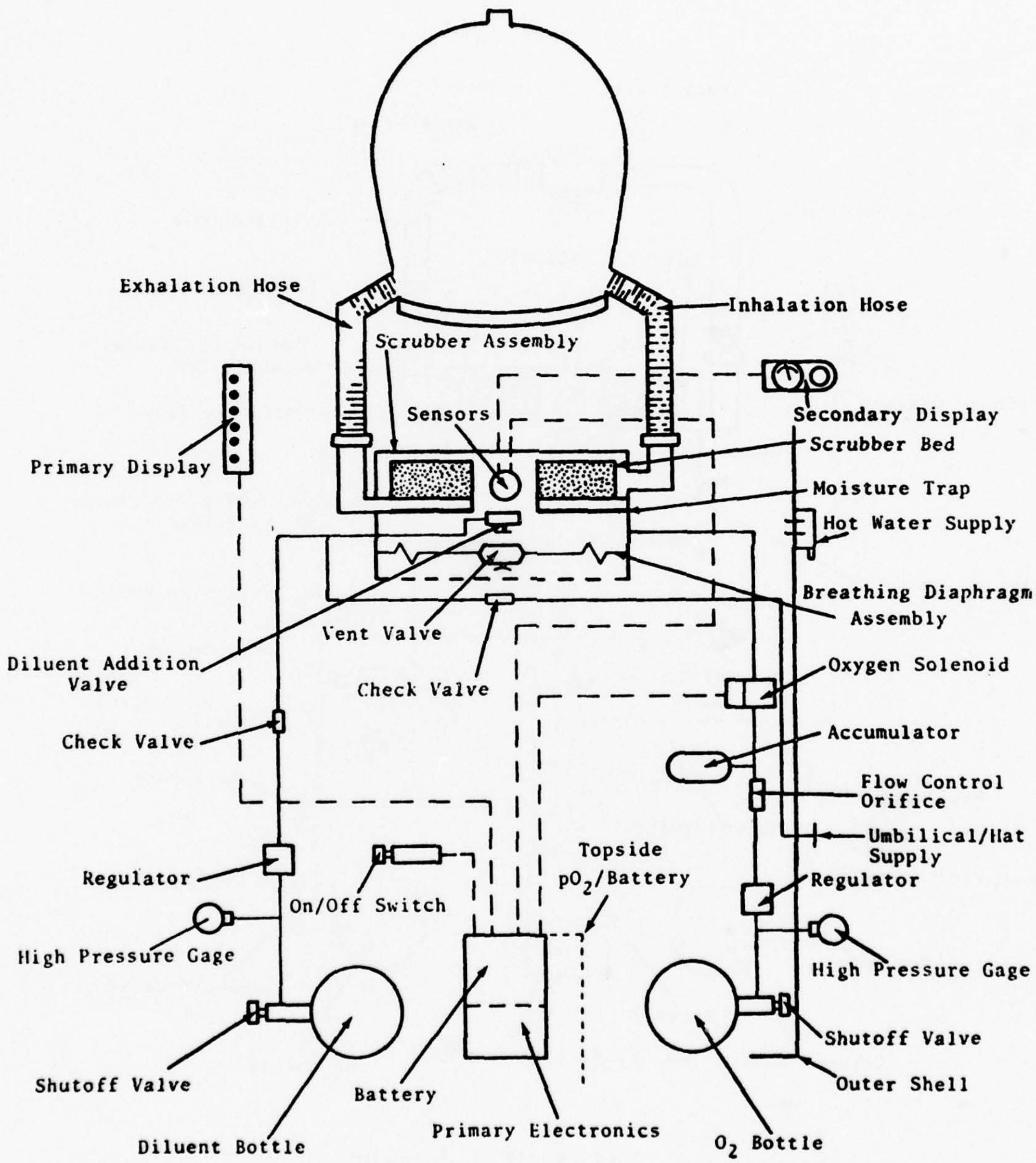

Figure 2-2. EX-17 UBA Schematic

buildup in the helmet. Earphones and a microphone provide the helmet with its communication capability.

The helmet's tee assembly makes closed-circuit operation possible. A diver operated helmet bypass exhaust valve functions to remove any water in the helmet and vent during open-circuit operation. A surface-supplied free flow valve on the helmet provides the emergency gas supply independent of the UBA backpack during open-circuit operation. A silencer reduces the noise level when the helmet supply valve is open.

Helmet design also incorporates a primary display bracket, liner pads and face cushion, neck seal and neck ring assembly, and breathing hoses.

SURFACE READOUT/ALARM UNIT

In contrast to the SLSS MK 1, the EX-17 is intended for use with an umbilical, permitting addition of a surface readout/alarm unit. Both the surface readout and the diver-worn secondary display give pO_2 readouts on all sensors and the UBA battery. However, the surface unit also has an automatic alarm which is activated by an out-of-tolerance breathing mixture, low battery output or an erratic sensor. The surface readout/alarm unit can be placed in a PTC, if the EX-17 mission requires.

CHECK VALVES

Two 10-psig check valves were installed in the umbilical supply line to direct the flow of respirable diluent gas from either the umbilical or the diluent bottle.

During normal closed-circuit operation, the respirable diluent bottle provides emergency gas volume make up in the breathing loop if the umbilical gas supply is lost. The bottle regulator should be set at no more than 150 psig and the umbilical supply no less than 180 psig. If umbilical pressure drops to within 10 psig of regulator pressure, the check valves close and the respirable diluent bottle supplies any gas required to keep the breathing loop of the UBA fully charged.

HOT WATER ENVELOPE

The EX-17 potential operating depth requirement necessitates heating the breathing gases in the life support system backpack. An umbilical-supplied hot water envelope performs this function.

O_2 SOLENOID ELECTRICAL LEAD

To facilitate measurement of O_2 consumption, electrical leads were added to EX-17 circuitry at the O_2 solenoid valve. This wiring is connected to the O_2 solenoid power supply. Additional of these leads enables NEDU medical personnel to record O_2 solenoid firing time. This modification is for physiological monitoring purposes only and does not impact overall EX-17 UBA performance or ultimate configuration.

O_2 AND DILUENT BYPASS REMOVAL

The O_2 bypass valve was removed from the SLSS MK 1 to

eliminate the possibility of a diver inadvertently opening the valve. The resulting O_2 poisoning could be fatal, particularly at 1,000 to 2,000 foot operating depths. Removal of the O_2 bypass insures that more than the 50cc in the accumulator will not be added at a given time.

Addition of an umbilical supply made the MK 1 diluent bypass unnecessary. If the umbilical were lost, the diluent add valve would keep the breathing loop charged and normal closed-circuit operation would continue. The diver would return to the PTC. Opening the helmet side valve provides the diver with more gas while closed-circuit mode continues, if this is required.

PIPING CHANGES

Addition of umbilical supply and removal of the O_2 and diluent bypass valves required piping changes to the MK 1 configuration. Changes made are evident by comparison of the MK 1 and EX-17 pneumatic assembly schematics in Figure 2-3. Items in the equipment list marked with a single asterisk have been added to the SLSS assembly; double asterisks indicate items deleted.

Elimination of the O_2 and diluent bypass valve assemblies required removal of piping to the couplings. The umbilical supply line was added to the diluent side of the system, entering the rig in the area where the O_2 bypass was formerly installed. (See Figure 2-2 for a detailed illustration.) Two check valves were installed in the supply line to direct flow from either the umbilical or bottle supply.

A hot water fitting was added to the piping to allow hot water heating of the rig.

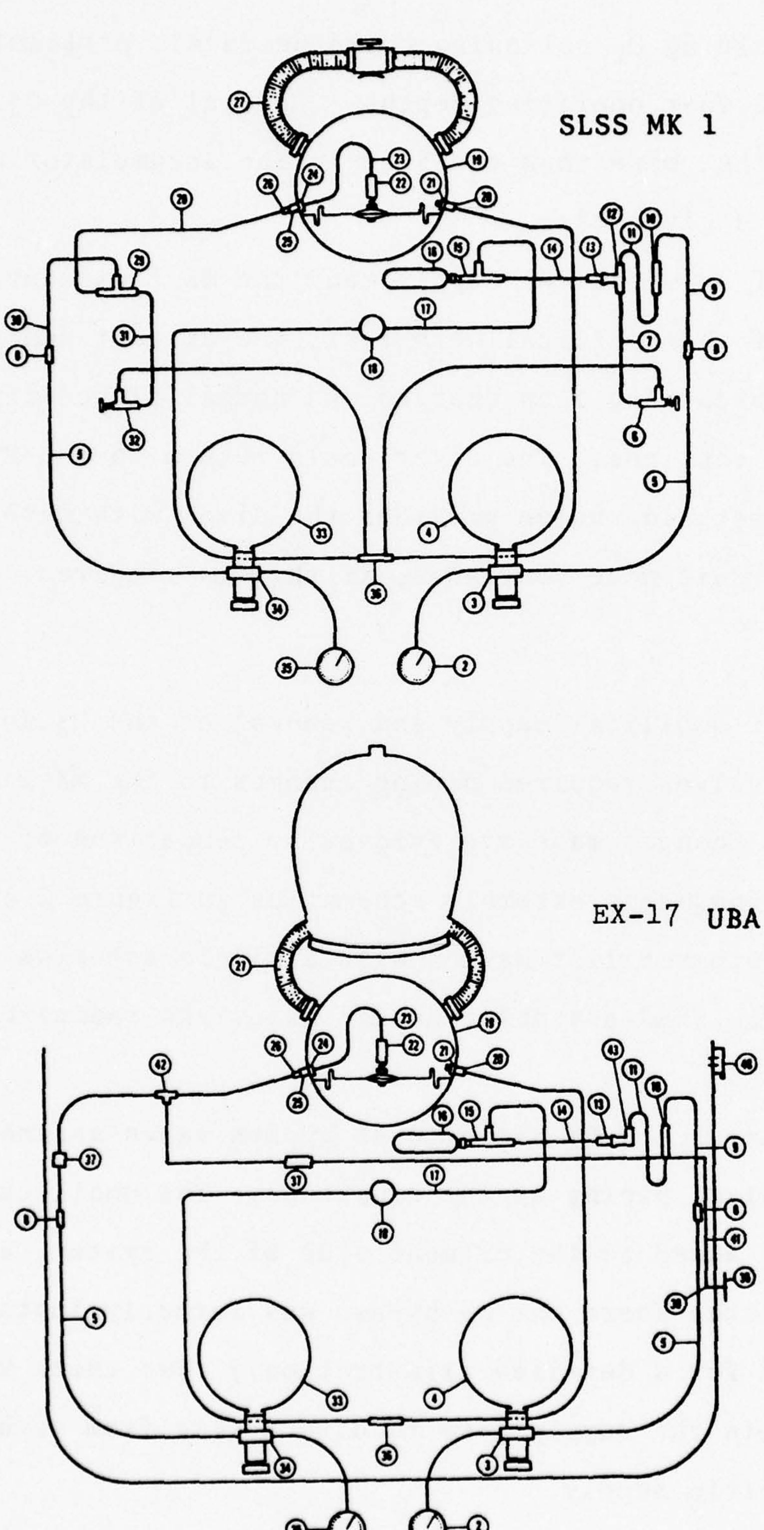

Figure 2-3. Pneumatic Assembly Schematics

Drawing Reference Number		Part Description
2		O_2 High Pressure Gage Assembly
3		O_2 Regulator
4		O_2 Bottle Assembly
5		Hose Assembly
6	**	O_2 Bypass Valve Assembly
7	**	Tube Assembly
8		Male Connector
9		Tube Assembly
10		Filter
11		Tube Assembly
12	**	Female Branch Tee
13		Orifice Assembly
14		Tube Assembly
15		Male Run Tee
16		O_2 Accumulator
17		Tube Assembly
18		Solenoid Assembly
19		Scrubber Assembly
20		Male Connector
21		O_2 Retainer, Seal
22		Diluent Valve Assembly
23		Diluent Tube Assembly
24		Diluent Retainer, Seal
25		Bulkhead Female Connector
26		Male Connector
27		Mouthpiece Assembly
28	**	Tube Assembly, Weldment
29	**	Union Tee
30	**	Tube Assembly
31	**	Tube Assembly
32	**	Diluent Bypass Valve Assembly
33		Diluent Bottle Assembly
34		Diluent Regulator
35		Diluent High Pressure Gage Assembly
36		Tube Assembly, Weldment
37	*	Check Valve, Stainless Steel
38	*	Elbow, Stainless Steel, ¼"
39	*	Tee, Stainless Steel, ¼"
40	*	Hot Water Fitting
41	*	Diluent Tube Assembly
42	*	Union Tee
43	*	Elbow

* Added for EX-17 configuration.

** Deleted from SLSS MK 1 configuration.

SECTION III

EX-17 TESTING

TEST OBJECTIVES

The objective of EX-17 test phase I, preliminary system evaluation, in the NEDU Test Pool was to familiarize divers with the EX-17 UBA.

Phase II instrumented testing in the Ocean Simulation Facility (OSF) was to establish system life support cability and mission reliability characteristics.

Table 3-1 is a detailed description of EX-17 testing phase I (dives 1 through 9, July 1977) and phase II (dives 10 through 31, August through December 1977).

NEDU tested the EX-17 during Deep Dive 77 to determine whether the EX-17 breathing apparatus would support a diver doing light, moderate, and heavy work at approximately 1,000 fsw (see dives 22 through 27).

Three canister breakthrough studies were performed on dives 28 through 31 to establish canister duration in 40°F water.

TEST PROCEDURE

The EX-17 UBA, as shown in Figures 1-1 and 2-2, was the major test equipment. During phase II testing, dive depths required use of a hot water suit. Sodasorb was the CO_2 absorbent throughout system evaluation. Predive and postdive checklists appear in Appendix C.

TABLE 3-1

EX-17 UBA TEST DIVES

Dive No.	Date	Depth	Water Temp.	Purpose	Duration (Hrs:Min)	Results Diver Comments
1	7-15-77	15'	68°F	Training	0:05	"Ease of breathing; comfortable"
2	7-18-77	15'	68°F	Training		"Very good rig"
3	7-18-77	15'	68°F	Training		"Helmet heavy on surface"
4	7-18-77	15'	68°F	Training		"Nice rig in the water"
5	7-18-77	15'	68°F	Training		"Low breathing resistance in all configurations"
6	7-18-77	15'	68°F	Training		
7	7-18-77	15'	68°F	Training	0:15	
8	7-19-77	15'	68°F	Training		"Could flood hat & clear with open circuit"
9	7-19-77	15'	68°F	Training		"Neck dam needs work"
10	8-26-77	75'		Manned Testing	1:00	"Helmet heavy on surface; light in water"
11	8-26-77	75'		Manned Testing	1:00	"Jocking of face seal difficult"
12		75'	40°F	Manned Testing		
13	10-19-77	22'	68°F	Baseline	0:46	Thread fitting on hose leak inlet
14	10-19-77	22'	68°F	Baseline	0:14	25-watt work rate
15	10-19-77	22'	68°F	Baseline	0:49	25-watt work rate
16	10-19-77	22'	68°F	Baseline	0:25	Sample line flooded
17	10-20-77	22'	68°F	Baseline	1:28	Work rates thru 200 watts
18	10-20-77	22'	68°F	Baseline	1:17	Work rates thru 175 watts
19	10-21-77	22'	68°F	Baseline	1:17	Work rates thru 150 watts; H.W. valve stuck
20	10-21-77	22'	68°F	Baseline	1:29	Work rates thru 175 watts
21	10-21-77	22'	68°F	Baseline	1:07	Work rates thru 125 watts
22	12-03-77	1054'	40°F	Manned Testing (Ergometer)	3:40	Work rates thru 100 watts
23	12-03-77	1040'	40°F	Manned Testing (Ergometer)	0:42	Work rates thru 25 watts; leaking check valves

TABLE 3-1

EX-17 UBA TEST DIVES (Continued)

Dive No.	Date	Depth	Water Temp.	Purpose	Duration (Hrs:Min)	Results Diver Comments
24	12-03-77	1030'	40°F	Manned Testing (Ergometer)	3:02	Work rates thru 125 watts
25	12-04-77	954'	40°F	Manned Testing (Ergometer)	1:15	Work rates thru 150 watts
26	12-04-77	943'	40°F	Manned Testing (Ergometer)	0:44	Work rates thru 100 watts
27	12-04-77	924'	40°F	Manned Testing (Ergometer)	0:55	Work rates thru 125 watts
28	12-05-77	862'	40°F	Canister Breakthrough	3:20	Changed diver when CO_2 0.5% SE (65 min. work; 75 min. on gas)
29	12-05-77	828'	40°F	Canister Breakthrough	3:02	CO_2 at end of work 1.0% SE (6:20 on canister; 5:52 min. work at 50 watts)
30	12-06-77	770'	40°F	Canister Breakthrough	2:05	Hot water bag open; no heating
31	12-06-77	750'	40°F	Canister Breakthrough	0:44	
					TOTAL 44:35	

To determine EX-17 support capability in phase II testing, divers performed graded exercise on a Collins pedal-mode ergometer. (See NEDU Research Report 1-76 for a full ergometer description.)

During dives 13 through 31, diver physiological and EX-17 functions of inspired O_2 and CO_2, oronasal differential pressure, inspired gas temperature, heart rate, and end tidal CO_2. Reference NEDU Test Number 77-34 for the dive protocol on dives 22 through 31.

OVERALL TEST RESULTS

The prototype EX-17 UBA demonstrated excellent life support capability and mission reliability characteristics at depths between 1,054 and 732 fsw. Diver confidence in the system was good.

Tests showed an O_2 consumption of 3.2 liters per minute at 150 watts, indicating the system can easily support a diver doing strenuous work at depth. Oronasal differential pressures and end tidal CO_2 levels were not excessive. (see Figures 3-1 and 3-2).

The Aquadyne helmet was satisfactory, but needs further modification. Divers reported problems in jocking the helmet and with the helmet clamp ring assembly for neck dam seal. Dive 23 was terminated due to leaks in the helmet nonreturn check valves.

Sensors read off scale during the test dives because they were not recalibrated at depth. Sensors should be calibrated at depth using a known gas and chamber atmosphere.

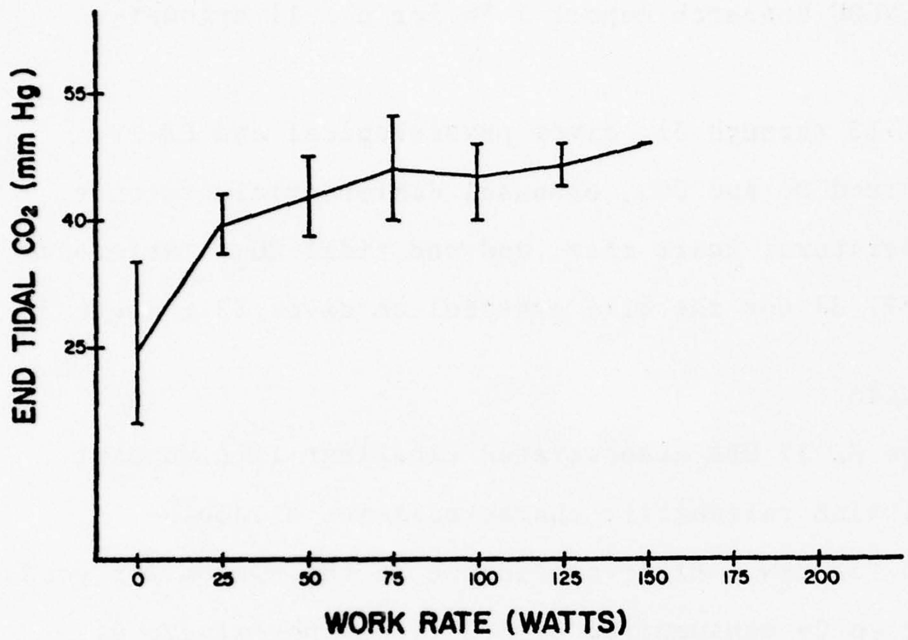

Figure 3-1. Mean and Range of end tidal pCO_2 at work rates

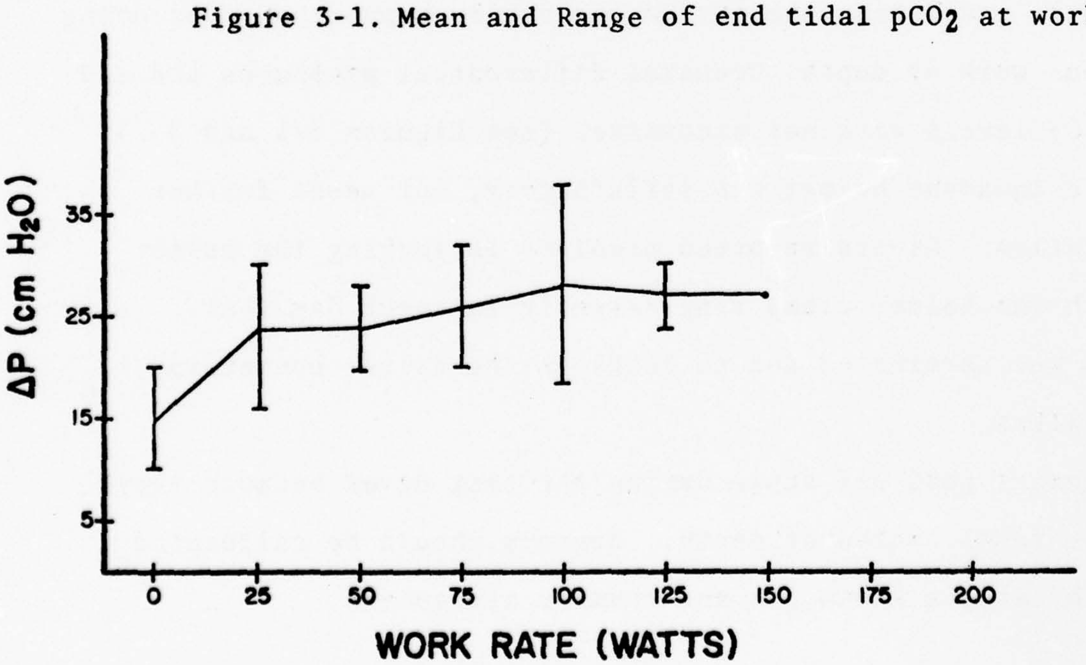

Figure 3-2. Mean and range of Oronasal differential pressures

During canister breakthrough testing, canister breakthrough occurred after 1-1/4 hours on the first canister, 31 minutes on the second, and 12 minutes on the third. The breakthrough point is defined as 0.5 percent surface equivalent (SEV) or 3.8 mm Hg.

There were several technical problems during canister breakthrough testing; i.e., a broken thermistor, intake valve leaks, and leaks in the EX-17 thermal jacket. The broken thermistor made measurement of CO_2 scrubber temperature impossible. Since the CO_2 scrubber will not function at temperatures below 45°F, this measurement is critical. The holes in the hot water envelope precluded heating canister gas. This factor was responsible for the progressive deterioration in canister duration, as canister duration is poor when the gas is cold.

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

Tests showed the EX-17 UBA is a viable deep diving life support system. Overall system performance met test objectives for life support and mission reliability at 1,000 fsw. A satisfactory initial configuration has been reached. However, further modifications are required to enhance system operation.

EX-17 UBA APPLICATIONS

The SLSS MK 1 was designed to provide swimmer support for special warfare and counterinsurgency teams. The EX-17 UBA can meet much broader mission requirements at greater depths than the MK 1. The system is best suited for saturation diving missions when used with a PTC.

The EX-17 UBA offers all the advantages of its SLSS MK 1 counterpart--increased diver mobility and safety, extended mission time, no gas bubbles, compactness, reduced helium costs, and minimized equipment maintenance. Low breathing resistance and neutral bouyancy enhance diver efficiency. The EX-17 can suppport a diver doing hard work with the added comfort of a dry helmet (versus a mouthpiece configuration).

RECOMMENDATIONS FOR FUTURE INVESTIGATION

If the EX-17 UBA is to function effectively and safely at depths from 1,000 fsw to 2,000 fsw, further investigation must be undertaken. NEDU is investigating the following:

1. Reduction of breathing resistance. Enlarging the canister inlet/outlet ports to 1-1/4 inch will reduce the oronasal differential pressures generated during heavy exercise.
2. Human factors investigation of helmet. Replacing the General Aquadyne helmet with a dry helmet more compatible with EX-17 configuration and operating requirements is envisioned.
3. Hot water heating of canister and gas. The hot water envelope housing the EX-17 assembly must be modified to prevent leaking. *NEDU is looking at a new type of* heating bag with Herculite as the thermal jacket material.
4. CO_2 absorption canister duration. The EX-17 CO_2 scrubber needs further modification to warm the canister bed and provide longer mission duration.
5. Diver harness. NEDU is designing a larger, webbed harness to replace the Herculite harness used in the test dives.

Specific areas for future research and development are:

1. Electronics accuracy/response time.
2. Partial pressure variation.
3. Pressure capacity of primary and secondary displays, wire terminations.
4. Gas leakage losses.
5. Respiratory rate/volume variations.
6. Interoperability with existing fleet hardware (e.g., helmets, deep dive systems).
7. Battery life.
8. Readability of electronic and pneumatic displays.
9. Overall performance at depths to 2,000 feet and an ambient water temperature of 40°F.
10. Life support reliability/maintainability at depths to 2,000 fsw

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APPENDIX A

SLSS MK 1 DESCRIPTION

APPENDIX A

SLSS MK 1 DESCRIPTION

The SLSS MK 1 is a closed-circuit, mixed-gas, self-contained underwater breathing apparatus (scuba). A battery operated electronic module maintains the swimmer's breathing gas at a predetermined partial pressure of oxygen (pO_2) via three oxygen sensors which measure and evaluate the pO_2 level. When an O_2 deficiency is indicated, the electronic module activates the solenoid valve in the oxygen pressure system to supply O_2 with $\pm$ 10 percent of the preset pO_2 level.

A battery powered primary display and an independent secondary display system powered by the oxygen sensors allow continual monitoring of pO_2 in the breathing loop. In the event of electronic module failure, primary display failure, battery failure or failure of any two of the three pO_2 sensors, the SLSS can still be manually operated and pO_2 controlled, as long as one pO_2 sensor remains operative.

The SLSS MK 1 comprises four independent subsystems.

1. Electronic assembly: disposal battery power supply, oxygen sensors, electronic control module, primary and secondary displays.
2. Pneumatic assembly: oxygen and respirable diluent gas storage bottles, oxygen and respirable diluent gas bottle pressure gages, stainless steel plumbing, solenoid valve, first stage regulator, filter, flow restrictor, accumulator, manual bypass valve.

3. Breathing loop: CO_2 removal system, flexible breathing diaphragm, moisture absorber, mouthpiece, flexible hose.
4. Equipment case assembly: backpack mounting base for all subassemblies, diver's harness, protective outer case.

The commerical version of the SLSS (Biomarine Industries' CCR-1000) was modified to meet the Specific Operational Requirement (SOR) 38-02 for a mixed-gas, closed-circuit scuba compatible for use with swimmer delivery vehicles (SDVs). Table A-1 describes the physical characteristics of the MK 1 system.

The SLSS MK 1 has the following operational characteristics.

1. Permits dive duration of six hours (with 70 percent of time above 21 feet).
2. Mission support reliability at least .95 at 80% confidence level.
3. Life support reliability at least .97 at 95% confidence level.
4. Compatible with mouth bit, full face mask or helmet.
5. Can be detached and donned safely underwater.
6. Compatible with SDV.
7. Use requires minimum training.

The primary advantages of the SLSS are its lack of air bubbles and increased bottom time, both attributable to the SLSS MK 1 rebreather capability. The system employs a scrubber containing a carbon dioxide absorbent; thus 95 percent of the gas the diver breathes is reused.

The SLSS MK 1 has the generally applicable advantages of increased diver efficiency and safety, minimized equipment maintenance, reduced helium costs, and greater reliability.

TABLE A-1

SLSS MK 1 PHYSICAL CHARACTERISTICS

Buoyancy*	+1.5 pounds (.68 kg) in salt water
Dimensional Envelope	Hydrodynamically styled
Length	23½ inches (59.6 cm)
Width	15-3/4 inches (40 cm)
Depth	10½ inches (26.6 cm)
Weight	57 pounds in air
Gas Bottle Capacities	
O_2 Bottle	21 ft^3 (6.4 m^3) at 3,000 psig (1360.7 K/m^2)
Diluent Bottle	21 ft^3 (6.4 m^3) at 3,000 psig (1360.7 K/m^2)
Breathing Loop Capacity	7.39 quarts (7 liters)
CO_2 Scrubber Capacity	
Sodasorb	7.25 pounds (3.28 kg)
Baralyme	8.25 pounds (3.74 kg)

* When submerged in seawater with diluent and O_2 flasks halfcharged and breathing diaphragm halfextended, the MK 1 is approximately neutrally buoyant.

APPENDIX B

EX-17 UBA EQUIPMENT LIST

PART DESCRIPTION	MANUFACTURER	PART NUMBER	QUANTITY
Swimmer Life Support System	Biomarine Industries	CCR-1000	
Spare Parts Package	"		
O_2 Sensor	"	200-506	9
O_2 High Pressure Gage Assembly	"	200-628 G1	1
O_2 Regulator	"	200-714	1
O_2 Bottle Assembly	"	200-632	1
Hose Assembly	"	200-681	3
Male Connector	"	SS-200-1-2	2
Tube Assembly	"	200-702	1
Filter	"	SS-2F-60	1
Tube Assembly	"	200-701	1
Orifice Assembly	"	200-607	1
Tube Assembly	"	200-690	1
Male Run Tee	"	SS-300-3-TMT	1
O_2 Accumulator	"	200-609	1
Tube Assembly	"	200-694	1
O_2 Solenoid Assembly	"	300-406	1
Scrubber Assembly	"	400-174	1
Male Connector	"	H859-2-4SS	1
O_2 Retainer, Seal	"	200-518	1
Diluent Valve Assembly	"	200-634	1
Diluent Tube Assembly	"	200-514	1
Diluent Retainer, Seal	"	200-517	1
Bulkhead Female Connector	"	SS-200-71-2	1
Male Connector	"	H854-2-2SS	1
Mouthpiece Assembly	"	300-403	

PART DESCRIPTION	MANUFACTURER	PART NUMBER	QUANTITY
Diluent Bottle Assembly	Biomarine Industries	200-633	1
Diluent Regulator	"	200-682	1
Diluent High Pressure Gage Assembly	"	200-628 G2	1
Tube Assembly, Weldment	"	300-407	1
Valve, O_2 Cylinder	"	300-432	1
Valve, Diluent Cylinder	"	300-433	1
Switch Assembly	"	300-401	1
Scrubber Cover	"	300-431	1
Scrubber Cover Seal	"	200-509	3
Scrubber, Rubber Band Seal	"	200-637	9
Seal Screw	"	200-604	2
Jumper Cable, Red	"	200-515 G1	2
Jumper Cable, Black	"	200-515 G2	2
Battery	"	200-608	160
Water Absorber	"	200-516	27
Water Absorber	"	200-511	9
Hardware Kit	"	200-725	1
Digital Multimeter	"	2	1
Diaphragm Assembly	"	300-352	1
Electronics Module Assembly	"	400-201	1
Secondary Display	"	200-712	1
Meter Movement	"	200-657	1
O-ring Kit	"	200-724	1
Band Assembly, Cylinder	"	200-631	2
Bulb, Primary Display	"	CM21-1	18

PART DESCRIPTION	MANUFACTURER	PART NUMBER	QUANTITY
Dry Helmet (Modified General Aquadyne DMC-7)	Innerspace Services	PP-1 GA	
On/Off Switch with Surface Alarm Interface	"		2
Electronics Kit	"		2
Harness, Complete	"		
Canister Adaptor Assembly	"	ISP-001 thru ISP-004, 2-131	
100-foot Umbilical	"		
Surface Alarm/pO_2 Readout	"		
Check Valves	Mobile Valve and Fitting Company	SS-2C-10	4
Leak Detector	"	NS-SNOOP	12
50-foot Hot Water Hose, 1/2"			
O_2 Gas Line			
Diluent Gas Line			
Diluent Tube Assembly			
Life Line			1
Elbow, SS, 1/4"			1
Tee, SS, 1/4"			1
Hot Water Fitting			1
Union Tee		SS-200-3	1
Elbow			1

APPENDIX C

PREDIVE AND POSTDIVE CHECKLISTS

PREDIVE CHECKLIST

NAME____________________________ RATE_________________ DATE______________

RIG #_____ SET POINT_______ CO_2 ABSORBENT__________ LOCATION____________

WATER TEMP._____o EVOLUTION_______ PREDIVE START TIME_________________

INITIALS

______ 1. Charge O_2 and diluent cylinders.
______ 2. Inspect all parts for dirt, deterioration, damage.
______ 3. Check/replace moisture absorbers, insuring 3 are in scrubber housing and 2 in scrubber cover with plastic washer.
______ 4. Inspect sensor wires.
______ 5. Fill CO_2 scrubber and install filler cap and rubber scrubber seal.
______ 6. Check O-ring and install scrubber; set spacer in place.
______ 7. Insure scrubber outer seal covers warning stripe.
______ 8. Sensor readings in air: #1 _____ #2 _____ #3 _____.
______ 9. Install scrubber cover and insure cover seal covers warning stripe.
______ 10. Battery voltage readings: + _____VDC - _____VDC.
______ 11. Install battery and battery housing cover; insure seal screw is tight.
______ 12. Install O_2 and diluent cylinder, lock in place and turn on.
______ 13. Record cylinder pressures: O_2 _______psig; Diluent _______psig.
______ 14. Turn ON-OFF switch to ON.
______ 15. Verify solenoid operation.
______ 16. Verify primary display operation.
______ 17. Breathe rig to verify set point pO_2 control.
______ 18. Sensor reading-rig at set point: #1 _____ #2 _____ #3 _____.
______ 19. Perform dip test by orally inflating breathing loop and totally submerging rig.
______ 20. Predive completion time: _______. Total Time: _______.
______ 21. Remarks (note deficiencies):

____
DIVER

____
DIVING SUPERVISOR

POSTDIVE CHECKLIST

INITIALS

_____ 1. Rinse rig in fresh water.

_____ 2. Record cylinder pressures: O_2 _______psig; Diluent _______psig. Remove psig batteries.

_____ 3. Secure gas cylinders and bleed down H.P.

_____ 4. Remove gas cylinders and stow in charging rack.

_____ 5. Insure ON-OFF switch is OFF; open battery housing and disconnect battery.

_____ 6. Open scrubber housing; remove scrubber and dump; rinse if necessary.

_____ 7. Remove and hang moisture absorbers to dry.

_____ 8. Record sensor readings in air: #1 _____ #2 _____ #3 _____.

_____ 9. Remove mouthpiece and breathing hoses, disinfect, rinse, and hang to dry.

_____10. Install dust cover.

_____11. Battery usage this dive: _______. Total: _______.

_____12. Remarks (note deficiencies and F.I.R. number if applicable):

____
DIVER

____
DIVING SUPERVISOR

GLOSSARY

ata	Atmospheres absolute
Baralyme	CO_2 absorbent
bpm	Breaths per minute
Canister breakthrough	The point at which CO_2 concentration in the breathing gas reaches 0.5 percent surface equivalent
cc	Cubic centimeter
CO_2	Carbon dioxide gas
P	Pressure differential
DDS	Deep dive system
fsw	Feet of seawater
ID	Internal diameter
Life support reliability	The probability that the life support system will carry the diver through his intended mission without abort due to critical or catastrophic hazard levels attributable to life support system malfunction or design deficiency
lpb	Liters per breath
Mission reliability	The probability that the system will carry the diver through his intended mission without abort attributable to system malfunction or design deficiency
NEDU	Navy Experimental Diving Unit, Panama City, Florida
OSF	Ocean Simulation Facility, Panama City, Florida
pO_2	Partial pressure of oxygen

Postdive time	The time during which the diving system is actively undergoing post-dive checkout
Predive time	The time during which the diving system is actively undergoing predive checkout
PTC	Personnel transfer capsule
SDV	Swimmer delivery vehicle
SEV	Surface equivalent
SLSS	Swimmer life support system
Sodasorb	CO_2 absorbent
SS	Stainless steel
Tidal volume	Volume of air breathed in and out of the lungs during normal respiration
UBA	Underwater breathing apparatus
UDT	Underwater demolition team
vO_2	Volume of oxygen